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The Influence of Antiperspirants on Foot Blister Incidence Following Road Marching

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Army Research Laboratory

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Abstract

The influence of antiperspirants on foot blister incidence during road marching was examined in 1,130 cadets from the U.S. Military Academy, West Point, New York. Cadets were separated into two groups that received either an antiperspirant or placebo preparation, and the study was double blinded. The antiperspirant was a commercially available substance (Drysol®) consisting of 20% aluminum chloride hexahydrate in anhydrous ethyl alcohol. The placebo was anhydrous ethyl alcohol without aluminum chlorhydrate. Cadets were briefed as a group and told to apply the antiperspirant to the entire foot for five consecutive nights before the road march, just before retiring for the evening. As part of their normal training, cadets completed a 21-km road march in about 6.5 hours, carrying a total load of about 33 kg. The cadets' feet were examined by trained personnel for blisters on the night before the march and after completion of the march. Many cadets were not present for the pre-march foot examination, some were on profile for the march, and some did not complete the march. The final sample size was 667 cadets with 328 in the antiperspirant group and 339 in the placebo group. There was a high rate of noncompliance with the treatment schedule: cadets used the preparations from 0 to 5 nights before the march. For cadets using the preparations at least three times before the march ($n=269$), the incidence of foot blisters was 21% for the antiperspirant group and 48% for the placebo group ($p<0.01$). However, reports of skin irritation were 57% for the antiperspirant group and 6% for the placebo group ($p<0.01$). These data suggest that antiperspirant may be an effective method of reducing foot blisters during road marching, but the side effects of skin irritation should be considered and preventive measures examined.

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EXECUTIVE SUMMARY

Foot blisters are the most common injury experienced by soldiers during road marching. Blisters can limit mobility, impair soldier performance, and lead to serious local and systemic infection. Frictional shearing forces seem to be the cause of most blisters, and moisture increases frictional forces on the skin. We hypothesized that blister incidence could be reduced if the amount of sweat produced during road marching could be curtailed through the use of antiperspirants.

Subjects were 1,130 first year cadets attending the U.S. Military Academy, West Point, New York. They completed a cadet health questionnaire that asked them about prior military experience, gender, ethnicity, injuries and illness in the last 12 months, foot type (normal, high arch, flat footed), cigarette smoking habits, daily smokeless tobacco use, alcohol consumption, and sleep habits. Cadets were then separated into two groups that received either an antiperspirant or placebo preparation. The antiperspirant was a commercially available substance (Drysol®) consisting of 20% aluminum chloride hexahydrate (a common ingredient of underarm deodorants) in anhydrous ethyl alcohol. The placebo was anhydrous ethyl alcohol without aluminum chlorhydrate. Cadets were briefed as a group and told to apply the preparations to the entire foot for five consecutive nights before the road march, just before retiring for the evening. The study was double blinded (neither the experimenters on site nor the subjects knew who was in each group until the conclusion of the investigation).

As part of their normal training, cadets completed the 21-km "Lake Frederick Road March" in about 6.5 hours, carrying a total load of about 33 kg. The cadets' feet were examined by trained personnel for blisters on the night before the march and after completion of the march. At the end of the march, subjects completed a short questionnaire that asked them how many nights they had applied the preparations, the type of socks worn, type of boots worn, and anything additional they had worn on their feet during the march (e.g., moleskin, adhesive tape, etc.).

Many cadets were not present for the pre-march foot examination, some were on profile for the march, some did not complete the march, and some resigned from the academy before the march. The final sample size was 667 cadets, with 328 in the antiperspirant group and 339 in the placebo group. There was a high rate of non-compliance with the treatment schedule: cadets used the preparations from 0 to 5 nights before the march. For cadets using the preparations at least three of the five nights before the march ($n=269$) 1) the incidence of foot blisters was 21%

for the antiperspirant group and 48% for the placebo group ($p < 0.01$); 2) 45% of cadets in the antiperspirant group and 17% of those in the placebo group reported that their feet did not sweat on the march ($p < 0.01$). Self-reports of skin irritation were 57% for the antiperspirant group and 6% for the placebo group ($p < 0.01$).

Possible confounding factors that could not be controlled were explored through the use of questionnaires. No differences existed between the antiperspirant and placebo groups ($p \geq 0.16$) in the numbers of subjects with previous road marching experience and previous military experience. There were generally no differences between the antiperspirant and placebo groups ($p \geq 0.13$) in the numbers of subjects wearing various material and substances (other than the preparations) on their feet. Two exceptions were that more subjects in the antiperspirant group wore moleskin and wore a laced boot (as opposed to the speed lace boot). When these subjects were removed from the data analysis, the antiperspirant group still had a lower blister incidence than the placebo group if the preparation was used at least three nights before the march.

Univariate analysis showed that risk factors for blisters in the placebo group included other than black ethnicity, a sickness in the last 12 months, no prior active duty military experience, use of smokeless tobacco, and flat feet (*pes planus*). The only blister risk factor in the antiperspirant group was non-attendance at a previous college military academy. Logistic regression analysis (separate models for placebo and antiperspirant groups) showed that all these were independent risk factors except for no previous active duty military experience in the placebo group.

These data suggest that antiperspirants may be an effective method of reducing foot blisters during road marching if applied for at least 3 nights before the march. The side effects of skin irritation should be considered and studied further to develop possible preventive measures. These preventive measures could include the use of a lower concentration of aluminum chloride hexahydrate, an altered treatment schedule (e.g., use every other night rather than every night), or addition of a cortisone-based compound to the antiperspirant preparation.

THE INFLUENCE OF ANTIPERSPIRANTS ON FOOT BLISTER INCIDENCE FOLLOWING ROAD MARCHING

INTRODUCTION

Foot blisters are typically painful but usually minor nuisances in most civilian endeavors. They generally require only simple first aid and a few days of limited activity (Levine, 1982). In military units, however, foot blisters can have much more serious consequences. In field conditions, completion of a mission may depend on the soldier's mobility and focused attention. Foot blisters can considerably reduce locomotion, impair concentration, and affect the soldier's ability to respond to emergencies. A broken blister can be a painful open wound and become more susceptible to infection because of the limited sanitation facilities in the field.

Moisture (Akers & Sulzberger, 1972; Naylor, 1955a) and frictional shearing forces (Comaish, 1973) seem to combine to increase the probability of blisters during physical activity. We hypothesized that the incidence of blisters could be reduced if the amount of sweat produced during physical activity could be diminished through the use of antiperspirants.

The purpose of this investigation was to examine the effectiveness of an antiperspirant preparation in reducing the incidence of foot blisters during prolonged road marching. A secondary purpose was to examine possible risk factors for march-related foot blisters. Road marching was chosen because it is a common soldiering activity and typically produces a high incidence of foot blisters (West, 1895; Knapik, Reynolds, Staab, Vogel, & Jones, 1992; Knapik, 1989; Knapik, Reynolds, Duplantis, & Jones, 1995).

BACKGROUND

The human cost of foot blisters to American military forces has been well documented but is not often appreciated. For example, one study reported that during a single strenuous 20-km road march, 69% of participating infantry soldiers had blisters, and 10% of the cases were severe enough to require medical attention (Knapik et al., 1992). Another investigation reported that during a 5-day, 100-mile road march at Ft. Hunter Liggett, California ("The Manchu 100"), 21% of soldiers required medical attention for blisters (Reynolds et al., 1997). In World War II, 2.4% of all hospitalizations for non-combat injuries were attributable to blisters (Reister, 1975). A study of Marine recruits during their 12-week boot camp showed that 14% of all sick call visits (44 of 323) were for blisters (Bensel, 1976). In one 6-month period at the Navy Recruit Training Command in Great Lakes, Illinois, 17% of all dispensary admissions (151 of 864) were

for cellulitis; 94% of the cellulitis cases (141 of 151) were on the foot, and 84% of the cases (137 of 151) were associated with blisters (Hoeffler, 1975).

Gross Observations and Histology of Friction Blisters

Experimental studies using rubbing techniques have been used to produce and study friction blisters (Akers, 1985). In these investigations, a variety of mechanical probes apply a constant force that repeatedly cycles over the skin in a linear or circular fashion. These studies demonstrate that a predictable series of events leads to blister formation. First, there is a slight exfoliation of the stratum corneum and a reddened region (erythroderma) forms in and around the zone of the rubbing (Naylor, 1955a; Sulzberger, Cortese, Fishman, & Wiley, 1966). The area encompassed by the erythroderma is referred to as a "hot spot" (Knapik et al., 1992; MacDonald, 1984), presumably because the subject experiences an increased sensation of heat. With continued rubbing of the area, the subject may suddenly experience a stinging or burning sensation, with a pale, narrow area forming around the reddened region. This pale area enlarges inward to occupy the entire zone where the rubbing is applied. The area becomes elevated over the underlying skin as it fills with fluid (Sulzberger et al., 1966).

Friction blisters are formed in the epidermis. A split occurs at the level of the stratum spinosum (Akers & Sulzberger, 1972; Naylor, 1955a; Sulzberger et al., 1966). Mechanical fatigue of the prickly cells in this area because of the repeated frictional forces is hypothesized to be the mechanism whereby the blister cleft develops (Comaish, 1973). The blister roof is composed of intact stratum corneum and stratum granulosum with normal, necrotic, and degenerated prickly cells on both sides of the split. The basal cell layer usually shows little insult and the junction between the dermis and epidermis remains undamaged. After a period of time (usually 1 to 2 hours), the area of the cleft fills with fluid because of hydrostatic pressure (Akers & Sulzberger, 1972; Hunter, McVittie, & Comaish, 1974; Naylor, 1955a; Sulzberger et al., 1966). Compared to plasma, the blister fluid has a low protein concentration and similar electrolyte concentration (Akers & Sulzberger, 1972; Cortese, Mitchell, & Sulzberger, 1968; Schmidt, 1970). Sweat can enter the blister cleft (Sulzberger & Cortese, 1968) and thus contribute to the fluid.

Cells in the blister roof stop synthesizing ribonucleic acid (RNA) and protein in less than 1 hour after the blister injury; thus, cells in the granular layer halt differentiation and never become cornified cells. Cells in the blister base continue to degrade for about 4 hours after the injury. Recovery begins after about 6 hours; cells in the blister base increase their uptake of amino acids and nucleosides of RNA and deoxyribonucleic acid (DNA). At 24 to 30 hours, high

mitotic activity is apparent in the base cells, and at 48 hours, a new granular layer is present. By 120 hours, cellular proliferation declines and a new stratum corneum can be seen. There are few inflammatory filtrates at any stage of recovery unless a secondary infection is present (Cortese, Fukuyama, Epstein, & Sulzberger, 1968; Epstein, Fukuyama, & Cortese, 1969).

Friction Forces and Blister Formation

When the skin contacts an object (e.g., shoe, sock, etc.) and an external force attempts to move the object across the skin, a frictional force will oppose the movement. As the external force is increased, the frictional force will increase and movement occurs when the external force exceeds the frictional force. Frictional forces are still present during movement but are somewhat reduced. Frictional effects are attributable to small irregularities on the surfaces of the skin and object (Akers, 1985; Bueche, 1972; Comaish & Bottoms, 1971; Naylor, 1955b).

The magnitude of a frictional force is proportional to the normal force (i.e., force of contact) according to this formula (Bueche, 1972):

$$F_f = \mu \cdot F_n$$

in which F_f = frictional force, μ = coefficient of friction, and F_n = normal (perpendicular) force. Naylor (1955b) found this relationship to hold for human skin; however, Comaish and Bottoms (1971) studied a wider range of forces and demonstrated an exponential relationship of F_f to F_n . The relationship could be described by the formula

$$F_f = \mu \cdot F_n^N$$

in which N = a power function < 1 . The nonlinear relationship was presumably attributable to an elastic deformation of the skin at low F_n . Coefficients of friction between the skin and various materials, objects, and substances range from 0.2 to 4.5 (Comaish & Bottoms, 1971; Highley, Coomey, DenBeste, & Wolfram, 1977; Naylor, 1955b).

The magnitude of the frictional force and the number of times a material or object cycles over the skin probably determines the likelihood of blister formation. As frictional forces increase, fewer cycles are required for blister formation (Akers, 1985; Comaish, 1973; Naylor, 1955a). This relationship is asymptotic at lower frictional forces (Naylor, 1955a), suggesting that there is a minimal force below which no blister will form regardless of the number of shear cycles (Comaish, 1973).

Frictional Forces, Moisture, and Blisters

The influence of moisture on blister formation has not been studied directly, but several investigations have examined the effects of moisture on frictional forces. Rubbing moist skin produces higher frictional forces than rubbing very dry or very wet skin (Akers & Sulzberger, 1972; Highley et al., 1977; Nacht, Close, Yeung, & Gans, 1981; Naylor, 1955b; Sulzberger et al., 1966). The reasons for this are not clear. However, it has been hypothesized that frictional forces on dry skin may result in exfoliation of the outermost cells from the stratum corneum, and these sloughed cells may provide a sliding lubrication analogous to graphite. Very wet skin may produce a hydrodynamic lubrication between the skin and other frictional surface. Moist skin may impede the movement of squamous cells by holding them to the skin by surface tension, thus increasing the frictional effect (Highley et al., 1977; Naylor, 1955b).

Antiperspirants and Friction Blisters

Antiperspirants applied to the foot have been demonstrated to decrease sweating (Darrigrand, Reynolds, Jackson, Hamlet, & Roberts, 1992; Juhlin & Hansson, 1968). The effectiveness of topical applications of antiperspirants for reducing blister formation is suggested from case studies showing the successful reduction of blistering events in people with recurrent blistering from mild exercise (Tidman & Wells, 1988; Tkach, 1982) and in an anecdotal report of reduced palmar blisters on oarsmen during training (Rook, Wilkinson, Ebling, Champion, & Burton, 1986).

Only one double-blinded, placebo-controlled, cross-over study has been conducted (Reynolds et al., 1995). This investigation used the antiperspirant aluminum zirconium tetrachlorohydrate glycine in a proprietary emollient base and studied subjects walking in the heat for 4 hours. Investigators found no difference between experimental and placebo conditions. However, sweating was not reduced in this investigation. It was hypothesized that the emollient may have interfered with the antiperspirant action. Emollients have been shown to reduce frictional forces in the short term but increase frictional forces over time (Nacht et al., 1981).

OBJECTIVES

The major objective of this study was to examine the effectiveness of an antiperspirant preparation without emollients on the incidence of foot blisters during road marching. Moisture (perspiration) on the skin increases frictional forces and an increase in frictional forces makes foot blisters more likely. Reducing moisture should reduce frictional forces and thus reduce foot

blister formation. The secondary objective of this investigation was to examine potential risk factors for foot blisters during road marching.

METHODS

Subjects

Subjects were 1,130 first year cadets at the U.S. Military Academy (USMA), West Point, New York. They volunteered for this investigation after a briefing about the purposes and risks of the study. They gave their informed voluntary consent to participate and signed a volunteer agreement affidavit in accordance with Army Regulation 70-25. There were initially 1,159 volunteers (96% of the first year cadet population) but 29 cadets reported previous problems with antiperspirants or alcohol-based preparations and were not permitted to participate in the study.

Experimental Design and Preparation Formulas

A double-blind, placebo-controlled experimental design was used. Half of the cadets received the placebo preparation and half the antiperspirant preparation. The placebo was a specially denatured alcohol (SDA) 40-2 anhydrous, consisting of 99.9% ethyl alcohol, 0.1% T-butyl alcohol, and 0.01% brucine sulfate. The antiperspirant was a commercially available preparation of a 20% solution of aluminum chloride hexahydrate in the same anhydrous ethyl alcohol base (Drysol®). Aluminum chloride hexahydrate is a common ingredient of underarm deodorants that has been shown to reduce sweating (Brandrup & Larsen, 1978; Darrigrand et al., 1992). The compound acts as a chemical irritant, increasing keratinization of the sweat ducts and blocking the exit of sweat from these glands (Fisher, 1967).

Procedures

Just after the informed consent briefing, volunteers completed a cadet health questionnaire that asked them about their previous military experience, gender, ethnicity, injuries, and illness experienced in the last 12 months, foot type (normal, high arch, flat footed), cigarette smoking habits, daily smokeless tobacco use, alcohol consumption, and sleep habits.

Five weeks later (6 days before the march), cadets were briefed in a large group about how to apply the preparations to the foot. They were provided a plastic bottle labeled with their name, subject number, and application instructions. Both the briefing and instructions on the

bottle noted that the preparation was to be applied for 5 consecutive nights before retiring for the evening. It was emphasized that the entire foot was to be covered (up the ankle to the top of the boot line) and that the preparation should be applied to a completely dry foot. Foam applicators on the bottle allowed subjects to easily spread the liquid preparations over their feet.

The cadets' feet were examined by trained technicians on the evening before the march. Cadets removed their boots, and technicians looked for blisters, broken blisters, and blood blisters. The location of each was recorded on the Blister Data Sheet (see Appendix A). A blister was defined as an elevated, fluid-filled vesicle lighter in color than the surrounding tissue. A broken blister was defined as a lighter colored, torn piece of skin under which part of the epidermis was exposed. A blood blister was defined as an elevated, fluid-filled vesicle darker in color than the surrounding tissue and presumably holding blood. These conditions were sharply distinguished from abrasions, callouses, bruises, and peeling skin in training and practice sessions provided technicians before the study. During the pre-march foot examination, cadets were verbally asked "Did you experience any irritation as a result of using the preparation?" A "yes" or "no" response was recorded.

The road march was 21 km long and was completed in about 6.5 hours. Two previous marches of 5 km and 13 km had been completed by the cadets in the 5 weeks before this march. For the 21-km march, cadets wore battle dress uniform (BDUs) with standard load-carrying equipment (LCE) and the all purpose lightweight individual carrying equipment (ALICE) pack. The total prescribed load (uniform, boots, and all equipment) had a mass of about 33 kg. The march was approximately 40% cross-country trails and 60% improved roads. Cross-country trails were mostly comprised of packed earth with some loose rocks and sand. The march was predominantly uphill with slopes ranging from flat to nearly 55° at one point. There were four rest stops of about 10 to 15 minutes. The rest stops were spaced 1.5 to 2.0 hours apart with water at each; fruit and glucose-electrolyte drinks were provided at the third stop.

Upon completion of the march, cadets removed their LCE and ALICE packs and were seated on a grassy knoll. They completed a post-march questionnaire (see Appendix B) which contained questions regarding how many nights they had applied the preparations, the type of socks worn on the march, type of boots worn, and anything additional they had worn on their feet (e.g., moleskin, adhesive tape, etc.). The cadets then removed their boots, and technicians examined their feet for blisters using the same criteria as during the pre-march examination. Temperatures and humidity during the march were obtained from a meteorological station at the USMA and are shown in Table 1.

Table 1
Temperature and Humidity During the Road March

Time of day (hour)	Temperature °C	Relative humidity (percent)
0500	19.0	-
1010	25.1	81
1224	28.4	84

Data Analysis

Unless otherwise specified, Pearson χ^2 statistics were used to test the hypothesis of no difference between treatment groups. When significant differences were found among variables having more than two levels, partitioned Pearson χ^2 statistics were used to test differences between levels.

Logistic regression was used to examine the interrelationship among the blister risk factors. Separate models were developed for the placebo and antiperspirant groups. A forward stepwise selection procedure was used with the enter and exit criteria set at $p=0.10$. Each level of a potential risk factor was compared to a reference level (except the reference level itself) to obtain coefficients and odds ratios. Confidence intervals were calculated from the standard errors of the estimated regression coefficients (Hosmer & Lemeshow, 1989).

RESULTS

A large number of cadets did not complete the study. Reasons included non-availability for the pre-march or post-march exam (because of other duties), medical profile for the march, non-completion of the march, and resignation from the academy before the march. The final sample size was 667 (59% of the volunteers) with 328 in the antiperspirant group and 339 in the placebo group.

There was also a high rate of noncompliance with the application schedule. The number of times the subjects used the preparations ranged from 0 to 5 days. Table 2 shows the number of cadets in both groups by days of preparations use.

Table 2
Number of Subjects by Group and Days of Preparation Use

	0 Days	1 Day	2 Days	3 Days	4 Days	5 Days
Antiperspirant	56	74	70	70	44	14
Placebo	65	76	57	51	52	38

Comparison Between Groups for Blisters, Sweating, and Irritation

Pre-march blister data sheets were compared to post-march sheets and only blisters developed on the march were considered in the data analysis. Cadets in the antiperspirant group had a 32% incidence of blisters, while cadets in the placebo group had a 44% incidence ($p<0.01$). Figure 1 shows foot blister incidence plotted by days of preparation use. The placebo and antiperspirant groups did not differ in subgroups using the preparations for 0 ($p=0.67$), 1 ($p=0.49$), or 2 ($p=0.85$) days; however, there were significant differences between subgroups using the preparations 3 ($p=0.01$), 4 ($p=0.01$), or 5 ($p=0.03$) days. Overall incidence of blisters in subjects using the preparations 0 to 2 days was 39% in the antiperspirant group and 41% in the placebo group ($p=0.62$); for subjects using the preparations 3 to 5 days, overall incidence of blisters was 21% in the antiperspirant group and 48% in the placebo group ($p<0.01$).

Figure 2 shows self-reports of foot sweating (obtained from the post-march questionnaire) plotted by group and days of use. In the antiperspirant group, 26% of the cadets reported that their feet did not sweat during the march compared to 12% in the placebo group ($p<0.01$). Placebo and antiperspirant groups did not differ in subgroups using the preparations for 0 ($p=0.67$), 2 ($p=0.17$), or 5 days ($p=0.13$); however, there were significant differences in groups using the preparations 1 ($p=0.02$), 3 ($p<0.01$), and 4 ($p=0.01$) days. Overall, for cadets using the preparations for 0 to 2 days, 15% of those in the antiperspirant group and 9% of those in the placebo group reported that their feet did not sweat ($p=0.07$); for cadets using the preparations 3 to 5 days, 45% of those in the antiperspirant group and 17% of those in the placebo group reported that their feet did not sweat ($p<0.01$).

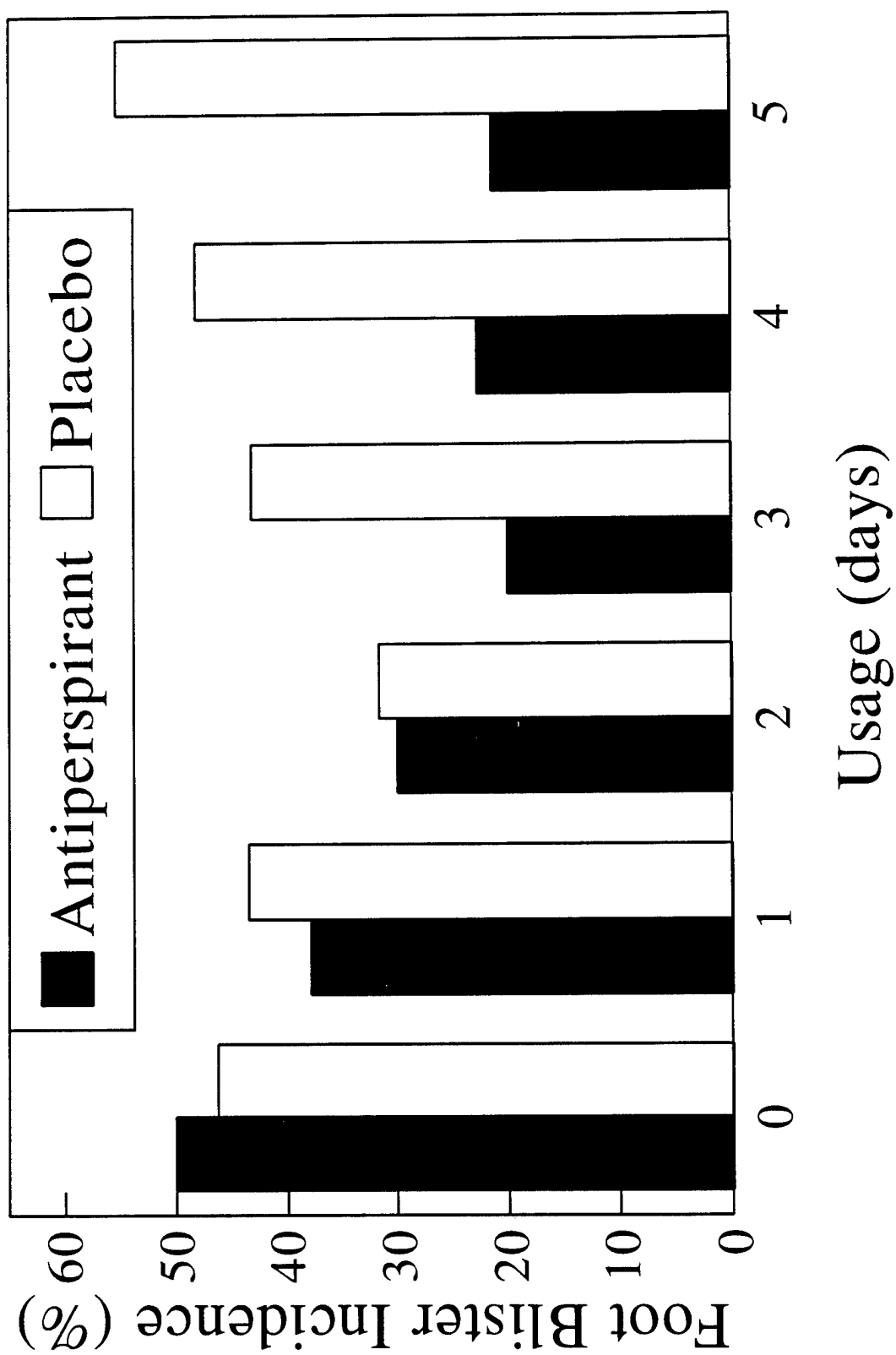


Figure 1. The influence of antiperspirants on foot blisters following a 21-km road march.

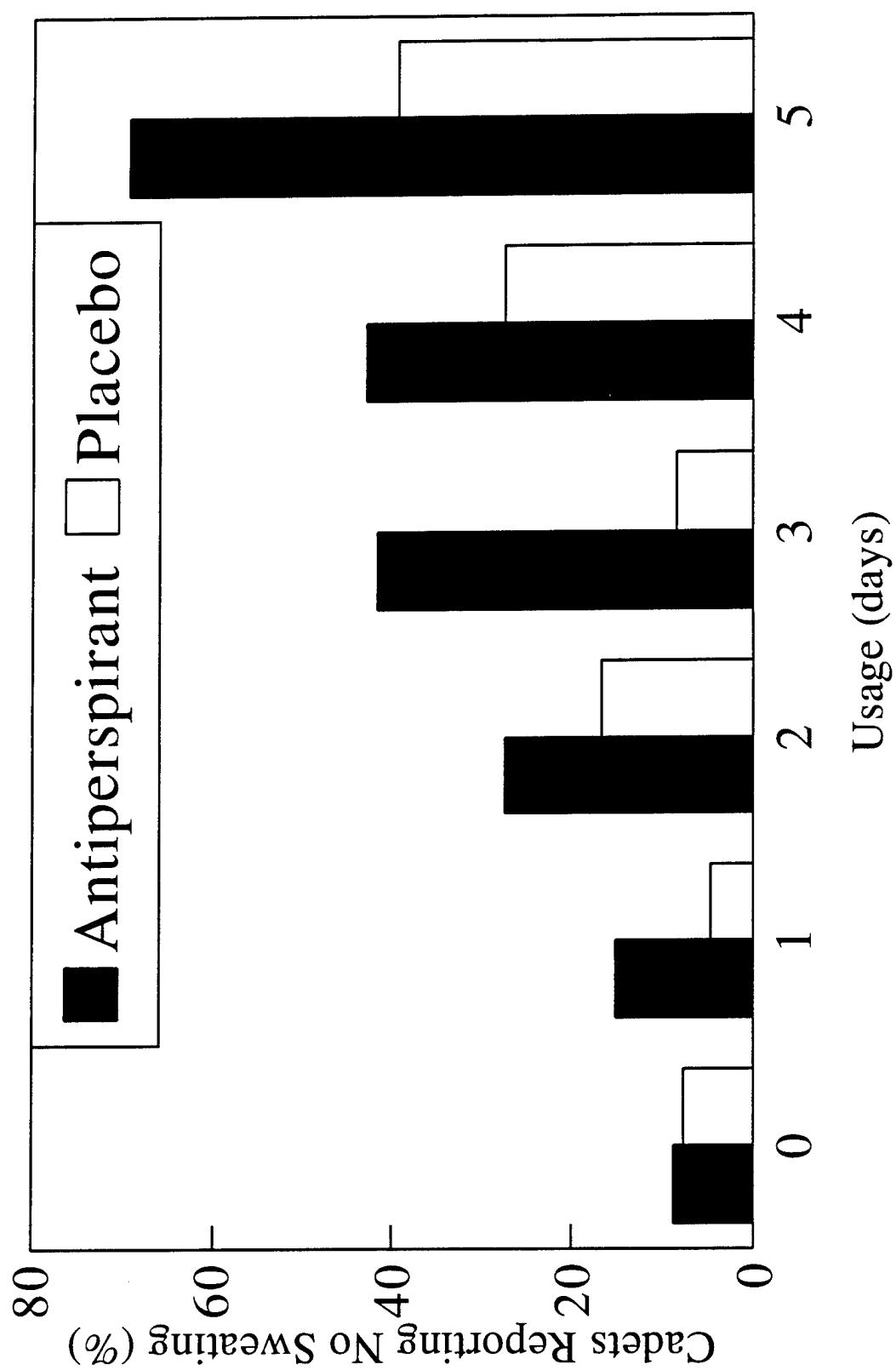


Figure 2. Self-reports of foot sweating following a 21-km road march.

Figure 3 shows the self-reports of irritation as a result of using the preparations (obtained from subjects verbally on the night before the march). In all the days-of-use subgroups, subjects who used the antiperspirant reported significantly more irritation ($p < 0.01$) than those using the placebo. The overall incidence of self-reported irritation was 57% in the antiperspirant group and 6% in the placebo group.

Comparisons Between Groups on the Basis of Military Experience

It was possible that previous road marching experience or previous military experience could have influenced the data. To address this possibility, questionnaires were used and responses examined looking for differences in number of cadets in the antiperspirant and placebo groups. Table 3 shows the distribution of cadets by their previous road marching experience and previous military experience. There were no differences between the antiperspirant and placebo groups in terms of the number of subjects responding "yes" or "no" to any of these questions.

Table 3
Previous Road Marching Experience and Military Experience of Cadets
(values following "yes" and "no" are the number of cadets in each group, and the
"p-value" is from the chi-square statistic comparing the two groups)

		0 to 2 days' use		3 to 5 days' use		0 to 5 days' use	
		AP ^a	Placebo	AP	Placebo	AP	Placebo
Previous road marching experience	yes	172	173	108	113	280	286
	no	28	25	20	28	48	53
	p-value	0.69		0.37		0.71	
Previous active duty military experience	yes	16	15	13	16	29	31
	no	182	179	112	123	294	302
	p-value	0.90		0.77		0.88	
Previous reserve military experience?	yes	12	6	3	7	15	12
	no	185	188	122	131	307	319
	p-value	0.16		0.26		0.64	
Previous ROTC experience?	yes	18	13	14	16	32	29
	no	180	181	111	123	291	304
	p-value	0.38		0.94		0.60	
Previous college military academy?	yes	9	9	10	13	19	22
	no	189	184	115	126	304	310
	p-value	0.96		0.70		0.69	
Previous high school military academy?	yes	8	7	3	1	11	8
	no	190	187	122	138	312	325
	p-value	0.82		0.26		0.44	

^aAP = antiperspirant

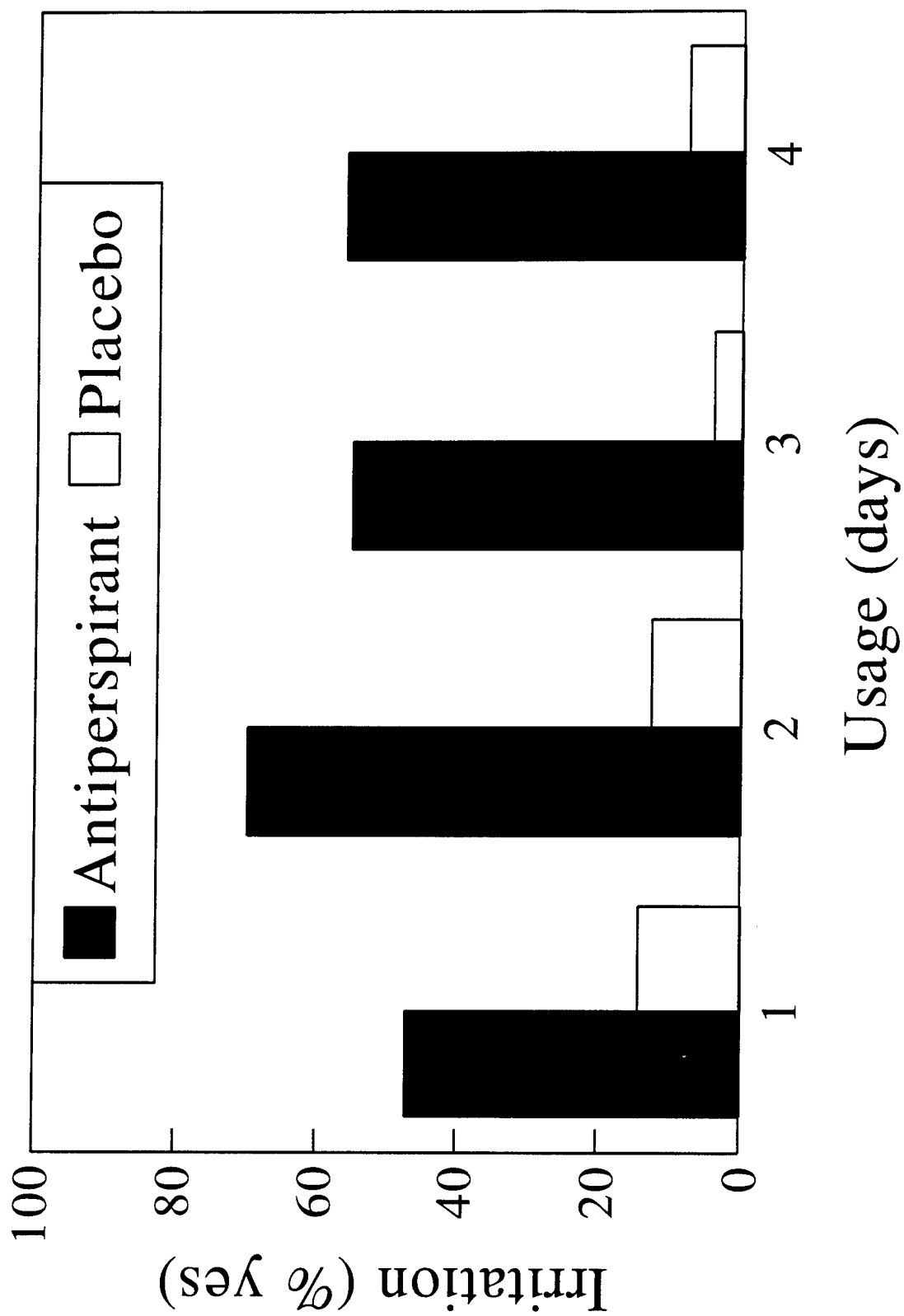


Figure 3. Self-reports of irritation for antiperspirants and placebo groups.

Comparisons Between Groups on the Basis of Materials or Substances Worn on the Foot

It was possible that materials or substances worn on the feet (other than the preparations) could have influenced the data. To address this possibility, questionnaires were again used. Table 4 shows the distribution of cadets based on self-reported materials or substances they used on their feet (other than the preparations). For the most part, there were no differences among the antiperspirant and placebo groups. Slightly more subjects in the antiperspirant group wore moleskin than did subjects in the placebo group ($p=0.1$). However, when subjects wearing moleskin were eliminated from the analysis, differences between groups were essentially unchanged; that is, for cadets using the preparations for 0 to 2 days, blister incidence was 35% in the antiperspirant group and 40% in the placebo group ($p=0.35$); for cadets using the preparations 3 to 5 days, blister incidence was 20% in the antiperspirant group and 46% in the placebo group ($p<0.01$).

Table 5 shows the distribution of cadets by self-reported type of socks worn on the march. Most subjects wore the standard black military sock composed of 50% wool and 50% cotton in the top and leg; and 50% (min) wool, 50% (max) nylon, and 20% (max) cotton in the heel and foot. The green military sock worn by the cadets had the identical composition. About half the subjects wore a second (inner) sock, and this was most often composed of a synthetic material. There were no differences among the antiperspirant and placebo groups for the numbers of subjects wearing the different sock systems.

Table 6 shows the distribution of cadets by self-reports of the types of boots worn on the march. When the boots were fitted to each cadet on the second or third day at the USMA, there were only two selections, the speed lace and laced types. The cadets had worn their boots for about 5 weeks before the march so they were well broken in. Table 6 shows that the laced boots were more likely to be worn by cadets in the antiperspirant group. However, when subjects wearing laced boots were eliminated from the data analysis, the results were essentially unchanged; that is, for cadets using the preparations for 0 to 2 days, blister incidence was 42% in the antiperspirant group and 42% in the placebo group ($p=0.92$); for cadets using the preparations 3 to 5 days, blister incidence was 17% in the antiperspirant group and 47% in the placebo group ($p<0.01$).

Table 4

Materials or Substances Worn by Cadets During the Road March
 (values in the "yes" and "no" rows are the number of cadets in each group, and
 the "p-value" is from the chi-square statistic comparing the two groups)

		0 to 2 days' use		3 to 5 days' use		0 to 5 days' use	
		AP ^a	Placebo	AP	Placebo	AP	Placebo
Wore moleskin	Yes	37	25	20	27	57	52
	No	163	173	108	114	271	287
	p-value	0.11		0.45		0.48	
Wore Spenco second skin	Yes	0	0	2	3	2	3
	No	200	198	126	138	326	336
	p-value	-		0.73		0.68	
Wore tincture of benzoin	Yes	1	1	3	2	4	3
	No	199	197	125	139	324	336
	p-value	-0.99		0.58		0.67	
Wore petroleum jelly	Yes	1	1	5	2	6	3
	No	199	197	123	139	322	336
	p-value	-0.99		0.2		0.29	
Wore adhesive tape	Yes	5	8	2	6	7	14
	No	195	190	125	135	320	325
	p-value	-0.39		0.2		0.14	
Wore other	Yes	23	29	10	18	33	47
	No	177	169	118	123	295	292
	p-value	-0.35		0.18		0.13	

^aAP = antiperspirant

Table 5

Self-Reports of Socks Worn by Cadets on the March

(values in all rows other than those labeled "p-value" are the number of cadets in each group;
 "p-value" is from the chi-square statistic comparing the two groups)

		0 to 2 days' use		3 to 5 days' use		0 to 5 days' use	
		AP ^a	Placebo	AP	Placebo	AP	Placebo
What type of socks did you wear on the march?	None	3	0	1	0	4	0
	Military green	14	11	6	11	20	22
	Military black	177	179	117	125	294	304
	White cotton	2	4	1	2	3	6
	Other	4	3	3	3	7	6
	p-value	0.39		0.65		0.27	
If you wore a second (inner) sock, what type was it?	None	101	86	57	67	158	153
	Military green	2	2	1	4	3	6
	White cotton	6	4	2	4	8	8
	Synthetic	82	96	60	61	142	157
	Other	2	1	0	0	2	1
	p-value	0.56		0.51		0.74	

^aAP = antiperspirant

Table 6

Self-Reports of Boots Worn by Cadets on the March

(values in all rows other than those labeled "p-value" are the number of cadets in each group;
 the "p-value" is from the chi-square statistic comparing the two groups)

		0 to 2 days' use		3 to 5 days' use		0 to 5 days' use	
		AP ^a	Placebo	AP	Placebo	AP	Placebo
What type of boots did you wear on the march?	Speed lace	151	168	79	109	230	277
	Laced	45	28	44	28	89	56
	Other	0	0	0	0	0	0
	p-value	0.03		0.05		<0.01	

^aAP = antiperspirant

Blister Risk Factors

Table 7 shows the univariate analysis of potential risk factors for blisters in the placebo group. Ethnicity emerged as a risk factor with individuals of black ethnicity at significantly lower risk than those of white ($p=0.02$), Asian ($p=0.02$), Hispanics ($p=0.08$), or other ($p=0.08$) ethnicity. There were no differences between white, Asian, Hispanics, or other ethnic groups ($p>0.25$). A sickness in the last 12 months, no previous active duty military experience, foot type, and the use of smokeless tobacco also appeared as risk factors.

Table 8 shows potential risk factors for the antiperspirant group. The only significant risk factor was non-attendance at a previous college military academy.

All variables listed in Table 7 and 8 were included in a logistic regression analysis in order to examine the interrelationship among the blister risk factors. Table 9 shows the variables in the final model for the placebo group based on 327 cadets with complete data for all variables (overall goodness of fit chi-square statistic $p<0.01$). Ethnicity other than black, sickness in the last 2 months, daily use of smokeless tobacco and foot type were independent risk factors for blisters. Table 9 also shows the variables in the final model for the antiperspirant group, based on 321 cadets with complete data (overall goodness of fit chi-square statistic $p=0.03$). The only independent risk factor was no previous college military academy experience.

DISCUSSION

The present study suggests that a 20% solution of aluminum chloride hexahydrate in anhydrous ethyl alcohol can reduce the incidence of foot blisters during prolonged road marching if applied at least 3 times on 3 separate days before the march. Compared to the placebo group, blister incidence was 56% lower for cadets using the antiperspirant at least 3 nights before the march, given the conditions of our study. There is the suggestion of an asymptotic dose response for the antiperspirant effect; that is, the greater the days of antiperspirant use, the greater the reduction in blister incidence, until 3 days, and after 3 days, blister incidence plateaus with no further reductions in incidence (see Figure 1). However, this is not supported by the statistical analysis which shows a similar decline in blister incidence for the placebo group over 0 to 2 days of use (see Figure 1).

Table 7

Univariate Analysis of Potential Risk Factors in the Placebo Group

Question	Response	Blisters (percent)	N	p- value ^a	Question	Response	Blisters (percent)	N	p- value ^a
Previous road march experience	Yes No	44.8 39.6	286 53	0.49	Foot type	Normal pes cavus pes planus	40.7 50.0 55.8	253 34 52	0.10
Previous ROTC experience	Yes No	44.8 44.4	29 304	0.97	Sick in last 12 months	Yes No	48.1 35.4	231 96	0.04
High school military academy	Yes No	50.0 44.3	8 325	0.75	Injured in last 12 months	Yes No	41.6 46.3	137 190	0.4
College military academy	Yes No	36.4 45.2	22 310	0.42	Smoke cigarettes	Yes No stopped	55.5 43.6 53.6	9 287 28	0.48
Active duty military experience	Yes No	29.0 46.0	31 302	0.07	Daily use smokeless tobacco	Yes No	59.3 43.1	27 299	0.10
Reserve military experience	Yes No	30.8 44.8	13 319	0.32	Consume alcohol	Yes No	39.2 43.5	102 214	0.66
Gender	Male Female	43.3 51.1	282 45	0.33	Hours sleep each night	<5 6-8 ≥9	36.8 46.2 35.7	19 266 42	0.35
Ethnicity	Black White Asian Hispanic Other	15.8 45.1 61.5 47.4 54.5	19 264 13 19 11	0.08					

^afrom chi-square statistic

Table 8

Univariate Analysis of Potential Risk Factors in the Antiperspirant Group

Question	Response	Blisters (percent)	N	p- value ^a	Question	Response	Blisters (percent)	N	p- value ^a
Previous road march experience	Yes No	32.5 27.1	280 48	0.46	Foot type	Normal pes cavus pes planus	31.5 23.5 37.3	235 34 59	0.39
Previous ROTC experience	Yes No	25.0 32.3	32 291	0.40	Sick in last 12 months	Yes No	32.4 29.3	238 82	0.60
High school military academy	Yes No	18.2 32.1	11 312	0.33	Injured in last 12 months	Yes No	28.5 34.1	144 176	0.28
College military academy	Yes No	10.5 32.9	19 304	0.04	Smoke cigarettes	Yes No stopped	50.0 30.4 36.0	4 289 25	0.61
Active duty military experience	Yes No	27.6 32.0	29 294	0.63	Daily use smokeless tobacco	Yes No	25.0 31.8	20 299	0.53
Reserve military experience	Yes No	33.3 31.5	15 307	0.89	Consume alcohol	Yes No	29.2 33.5	106 206	0.45
Gender	Male Female	30.4 40.0	280 40	0.22	Hours sleep each night	<5 6-8 ≥9	30.8 31.0 37.5	26 261 32	0.76
Ethnicity	Black White Asian Hispanic Other	21.1 32.1 35.7 26.1 32.1	19 249 14 23 12	0.95					

^afrom chi-square statistic

Table 9

Logistic Regression Results From Forward Stepping Procedure
With Foot Blister Incident as the Independent Variable

Risk factor	Odds ratio	95% confidence interval (odds ratios)	Coefficient	Standard error of coefficient	p-value ^a
PLACEBO GROUP					
Ethnicity					
Black	1.0	----			
Other	5.2	1.5--18.7	1.6559	0.649	0.01
Sick in last 12 months					
No	1.0	----			
Yes	1.9	1.2--3.2	0.664	0.258	0.01
Daily use of smokeless tobacco					
No	1.0	----			
Yes	2.3	1.0--5.4	0.818	0.441	0.06
Foot type					
Normal	1.0	----			
Pes cavus	1.3	0.5--3.4	0.283	0.485	0.56
Pes planus	2.0	1.1--3.7	0.677	0.321	0.04
ANTIPERSPIRANT GROUP					
Previous college military academy					
Yes	1.0	----			
No	4.2	1.0--18.5	1.433	0.756	0.06

^afrom Wald statistic

Since moisture increases friction (Akers & Sulzberger, 1972; Naylor, 1955a) and friction appears to be the cause of most foot blisters seen during physical activity (Comaish, 1973; Knapik et al., 1995), we hypothesized that reducing sweat through the use of antiperspirants

should reduce blister incidence. We did not measure sweat production directly, but we did ask subjects if their feet sweat during the march. Of the cadets who used the preparations at least 3 times before the march, 45% of those in the antiperspirant group and 17% in the placebo group reported that their feet did not sweat. These data tend to support the idea that sweat was reduced in the antiperspirant group, and this may have been the mechanism for the reduction in blister incidence. Darrigrand et al. (1992) provided more direct evidence of the sweat-reduction capability of a 24% aqueous solution of aluminum chlorohydrate. They measured sock and boot weight before and after a 1-hour treadmill walk in the heat (32° C, 65% relative humidity) and found a 55% reduction in total sweat accumulation with the antiperspirant. Foot skin temperature was not different between control and antiperspirant groups, suggesting that local thermoregulation was not affected by the antiperspirant.

Our results differ from those of Reynolds et al. (1995) who reported that an antiperspirant (20% aqueous solution of aluminum zirconium tetrachlorohydrate glycine) with emollient did not reduce the incidence of foot blisters during 4 hours of walking on a treadmill. However, the emollient used in the antiperspirant preparation in that study may have interfered with the antiperspirant action (Nacht et al., 1981). The preparation did not reduce sweating as measured by weighing socks after the walk. Darrigrand et al. (1992) also reported that a 24% solution of aluminum chlorohydrate resulted in no significant reduction in blister incidence in soldiers walking on a treadmill for 1 hour. However, a re-analysis of their data shows that blisters were actually reduced. Table 10 presents these data (two antiperspirant preparations were tested). All nonparametric tests for related samples (Friedman Test, Cochran's Q, and Kendall's W) showed an overall reduction in blister incidence when the placebo group is compared to the aluminum chlorohydrate group ($p < 0.01$ for all tests).

Table 10

Contingency Table Showing Distribution of Blister Incidence in the Study
by Darrigrand et al. (1992)

	Control	Aluminum chlorhydrate preparation	Aluminum zirconium tetrachlorohydrate glycine preparation
Blisters	8	0	3
No blisters	8	16	13

Noncompliance

There was a high rate of noncompliance with the prescribed 5-day treatment schedule. Cadets self-selected into the subgroups represented by the various days of usage. It may be argued that this self-selection makes our data questionable. This is because subjects who more closely followed the treatment schedule may have been more highly motivated and possibly more careful to take actions to avoid blisters. Several counter arguments should be considered. First, subjects were randomly assigned to groups, and individual motivation would be expected to have been evenly distributed between the antiperspirant and placebo groups. If motivation was greater in one group, greater compliance would be expected in that group. In fact, there was a similar number of antiperspirant and placebo subjects in the days-of-use subgroups (see Table 2). Second, we looked at some factors that might have reflected actions to take better care of the feet (use of socks, moleskin, adhesive tape, etc.) and found that the number of subjects with these factors were about the same in the antiperspirant and placebo groups. Finally, a number of subjects did follow the treatment protocol and applied the preparations to their feet for the entire 5 nights. The reduction in blister incidence in antiperspirant 5-day usage subgroup was as large as that in the subgroups applying the preparations for 3 or 4 days.

Noncompliance with prescribed regimens is a common problem often cited in the literature (Fletcher, 1989; Greenburg, 1984; Griffin, 1990). Compliance can be defined as the extent to which an individual's behavior coincides with a prescription (Griffin, 1990; Litt & Cuskey, 1980). Compliance rates vary widely, probably depending on the numerous factors that can influence the decision to comply. In adolescent populations, overall compliance rates are about 50%, with a range of 20% to 80% (Litt & Cuskey, 1980), similar to those found in adult populations (Greenburg, 1984; Griffin, 1990). In our study, the average \pm standard deviation (SD) number of days that cadets reported using the preparations was 2.0 ± 1.4 in the antiperspirant group and 2.2 ± 1.7 in the placebo group ($t(665)=1.19$, $p=0.23$) for compliance rates of 40% and 44%, respectively.

Although we did not query cadets about why they did not follow the treatment schedule, some assumptions can be made. The subjects were in cadet basic training, and application of the preparations competed with other activities that the cadets had to perform as part of this very busy time. Preparation application time was relatively short (about 1 minute for each foot), but drying time was longer (10 to 15 minutes). Thus, cadets may have elected not to apply the preparations in order to accomplish other tasks they perceived as more important. For the antiperspirant group, irritation was probably not a reason for discontinuing preparation application; the number of cadets in the usage subgroups were about the same in antiperspirant and placebo groups.

Irritation

The verbal responses of subjects suggested that considerably more skin irritation occurred in the antiperspirant group. The night before the march, 57% of subjects in the antiperspirant group reported irritation, compared to only 6% in the placebo group. We collected only a “yes” or “no” response from subjects, so we do not know the nature of this irritation. Some subjects did elaborate, saying that they experienced a stinging and burning sensation upon application, and some subjects noted rash formation.

Darrigrand et al. (1992) reported a 44% incidence of irritant dermatitis (7 of 16 subjects) in soldiers using a 24% aqueous solution of aluminum chlorohydrate for 3 days. Reynold et al. (1995) reported no irritant dermatitis when an emollient was combined with aluminum zirconium tetrachlorohydrate glycine but this compound did not reduce sweating or blister incidence. There may be methods of reducing the irritation while preserving the favorable antiperspirant property. These include 1) the use of lower concentrations of aluminum chlorohydrate, 2) changing the treatment schedule (e.g., use every other or every third night), or 3) by combining the active ingredient (aluminum chloride hexahydrate) with a cortisone-based preparation. A common-sense approach is to discontinue using the preparations if irritation occurs.

Other Considerations and Potential Confounders

One difficulty with this study was the limited access we had to the cadets. Subjects were going through cadet basic training, and the requirements of the study, although programmed into the training schedule, had low priority. For the pre-march screen, our research team was only permitted 90 minutes in the barracks to complete the pre-march foot examinations. While all available cadets were screened in this time, if a cadet was not present, he or she was not screened and that person's data could not be considered. A number of subjects were on detail or obtaining equipment for the next day march during this time. Also, during the post-march screen, some cadets were required to perform other tasks immediately upon arrival at Lake Frederick. These cadets could not be screened because of the limited time we had access at Lake Frederick.

We anticipated a number of other possible confounders and attempted to see how serious these were, using questionnaire techniques. We assumed that if the number of cadets with these possible confounders was similar in the antiperspirant and placebo groups, the influence of the potential confounder would be minimal. Possible confounders included previous military experience, socks, types of boots, and other items or substances placed on the foot. Cadets with previous road march or military experience could have known how to minimize blisters by caring

for their feet more effectively. Cadets could have worn materials on their feet (e.g., moleskin, adhesive tape, petroleum jelly) that could have influenced blister incidence, although there have been few studies specifically addressing any of the materials we asked about (Knapik et al., 1995). Cadets may have worn different socks and it is known that particular sock systems can reduce the likelihood of blisters (Herring & Richie, 1990; Knapik, Hamlet, Thompson, & Jones, 1996). The type of boot worn may also affect blisters if one type is more likely to increase frictional effects (Knapik et al., 1995). Of all these variables, only the type of boot worn and moleskin use differed in terms of the number of cadets in the placebo and antiperspirant groups. When subjects wearing different boots or those wearing moleskin were eliminated from the analysis, the results were essentially unchanged: cadets using the antiperspirants at least 3 times still had a lower blister incidence than those using the placebo. Thus, it appears that these possible confounders had a minimal influence on the outcome of the investigation.

Risk Factors for Foot Blisters

Potential risk factors that were examined in this study were based on suggestions from previous studies (Knapik et al., 1992; Knapik et al., 1996; Knapik et al., 1995; Reynolds et al., 1995; Reynolds et al., 1997) as well as advice from physicians, physiologists, physical therapists, trainers, soldiers, and former soldiers who provided input at various times during the planning for this study. We found that independent risk factors for blisters in the placebo group included ethnicity other than black, flat feet (*pes planus*), daily use of smokeless tobacco, and a sickness in the last 12 months. In the antiperspirant group only lack of previous military experience was a risk factor. Each of these is discussed next.

Ethnicity

The fact that black ethnicity was protective for blisters is in consonance with another study examining road marching injuries during a 161-km march conducted during a 5-day period (Reynolds et al., 1997). Overall risk of injury in military activities is only marginally associated with ethnicity (Jones et al., 1993; Tomlinson, Lednar, & Jackson, 1987). However, the pattern of injuries may vary so that those of certain ethnic backgrounds may be at higher risk for some injuries and lower risk for others. For example, individuals of black ethnicity have a lower incidence of stress fractures than those of white ethnicity (Brudvig, Gudger, & Obermeyer, 1983; Gardner et al., 1988), presumably because of higher bone density in blacks (Trutter, Broman, & Peterson, 1960).

Differences have been reported in the mechanical and physiological properties of black, white, and Hispanic skin. On the dorsal forearm, the elastic modulus is lower in blacks than whites or Hispanics, indicating that the same stress causes less deformation in black skin (Berardesca, deRigal, Leveque, & Maibach, 1991). Reduced deformation may reduce mechanical fatigue in the stratum spinosum, making blisters less likely. However, no study has specifically examined mechanical differences in the foot, which has a thicker horny layer than other areas of the body (Sulzberger et al., 1966), or specifically examined possible stratum spinosum differences, where friction blisters occur (Akers & Sulzberger, 1972).

Black skin is less susceptible to chemical irritation than white or Asian skin, indicated by the time to vasodilatation following application of the irritant (Kompore & Tsuruta, 1993; Marshall, Lynch, & Smith, 1919; Weigand & Gaylor, 1974). When blacks are compared to whites, more cell layers are present in the abdominal area of blacks (Weigand, Haygood, & Gaylor, 1974) but not in the facial area (Montagna & Carlisle, 1991). Black skin is more resistant than white skin to tape stripping (Weigand & Gaylor, 1974). When the stratum corneum is removed by tape stripping, peripheral vasodilatation in response to chemical irritants still takes longer in blacks than in whites or Asians (Kompore & Tsuruta, 1993), suggesting that there are differences in skin layers below the stratum corneum. There is some evidence that black skin contains more epidermal lipids (Reinertson & Wheatley, 1959), possibly indicating more intracellular cohesion (Kompore & Tsuruta, 1993). Studies examining biochemical and biomechanical properties of the foot may add more insight into why black skin appears to be less susceptible to friction blisters.

Foot Type

Self-reported flat feet were associated with the increased likelihood of blisters. It is possible that flat feet result in more of the foot surface area being exposed to frictional forces since more of the foot is in contact with potential frictional surfaces on the boot. No other study has examined blister incidence in subjects with flat feet, but one reported overall injury incidence in flat-footed individuals compared to those of different foot types. Cowan, Jones, and Robinson (1993) demonstrated that basic trainees with low arch height (flat feet) were at substantially lower risk of lower extremity musculoskeletal injury during basic training than normal arch or high arched trainees. It is not clear if blisters were included in their definition of injury.

Tobacco Use

We found that daily smokeless tobacco use was an independent risk factor for blisters but smoking was not. In our study, there was a small number of smokers (13 of 642) which considerably reduced statistical power. It is well established that cigarette smoking is associated with overall risk of injury in both military and civilian samples (Amoroso, Reynolds, Barnes, & White, 1996), and had the number of smokers been larger in our study, similar results may have been expected.

The data about associations between smokeless tobacco use and injuries are not clear, and contradictory information has emerged (Amoroso, Dettori, & Reynolds, 1996; Reynolds et al., 1997). Reynolds et al. (1997) found no relationship between smokeless tobacco use and blister incidence during a 161-km road march conducted by infantry troops during a 5-day period. In their study, the smokeless tobacco question was worded as follows: "Do you consume or have you ever consumed smokeless tobacco? Specify quantity and frequency." This question differs considerably from the one used in this study which asked, "How many times per day do you use smokeless tobacco (chewing tobacco, snuff, pouches, etc.)?" In the study by Reynolds et al. (1997), the question addressed whether smokeless tobacco had been used at any time in one's life (including currently); in the current study, the question addressed daily, current use. Thus, it may be daily, current smokeless tobacco use that is a blister risk factor.

Studies about smokeless tobacco are far fewer in number than those addressing cigarette smoking. This is probably because widespread use of smokeless tobacco has just recently returned to this country. Earlier in American history, smokeless tobacco use was much more common than cigarette smoking (Christen, Swanson, Glover, & Henderson, 1982). In our study, prevalence of daily smokeless tobacco use was 7% (47 of 645) of the first year cadet sample, which is slightly lower than the 8% to 10% found in other U.S. Army samples (Bahrke, Baur, Poland, & Connors, 1988; Kenny, Quigley, & Regennitter, 1996).

A suggested mechanism of action for the effects of smokeless tobacco on blister likelihood is illustrated in Figure 4. Smokeless tobacco causes a dose-dependent vasodilation in the buccal mucosa at the site of application (Huckabee, Barnes, A, Fan, & Downey, 1993). Nicotine is readily absorbed from buccal and nasal mucosa (Benowitz, 1986; Benowitz, Jacobs, & Yu, 1989; McNabb, Ebert, & McCusker, 1982). Nicotine activates the sympathetic nervous system, resulting in increased plasma levels of epinephrine and norepinephrine (Cryer, Hammond, Santiago, & Shah, 1976). It has been amply demonstrated that nicotine injection (Dengerink, Wright, Miller, & Goodwin, 1985; Rottenstein, Peirce, Russ, Felder, &

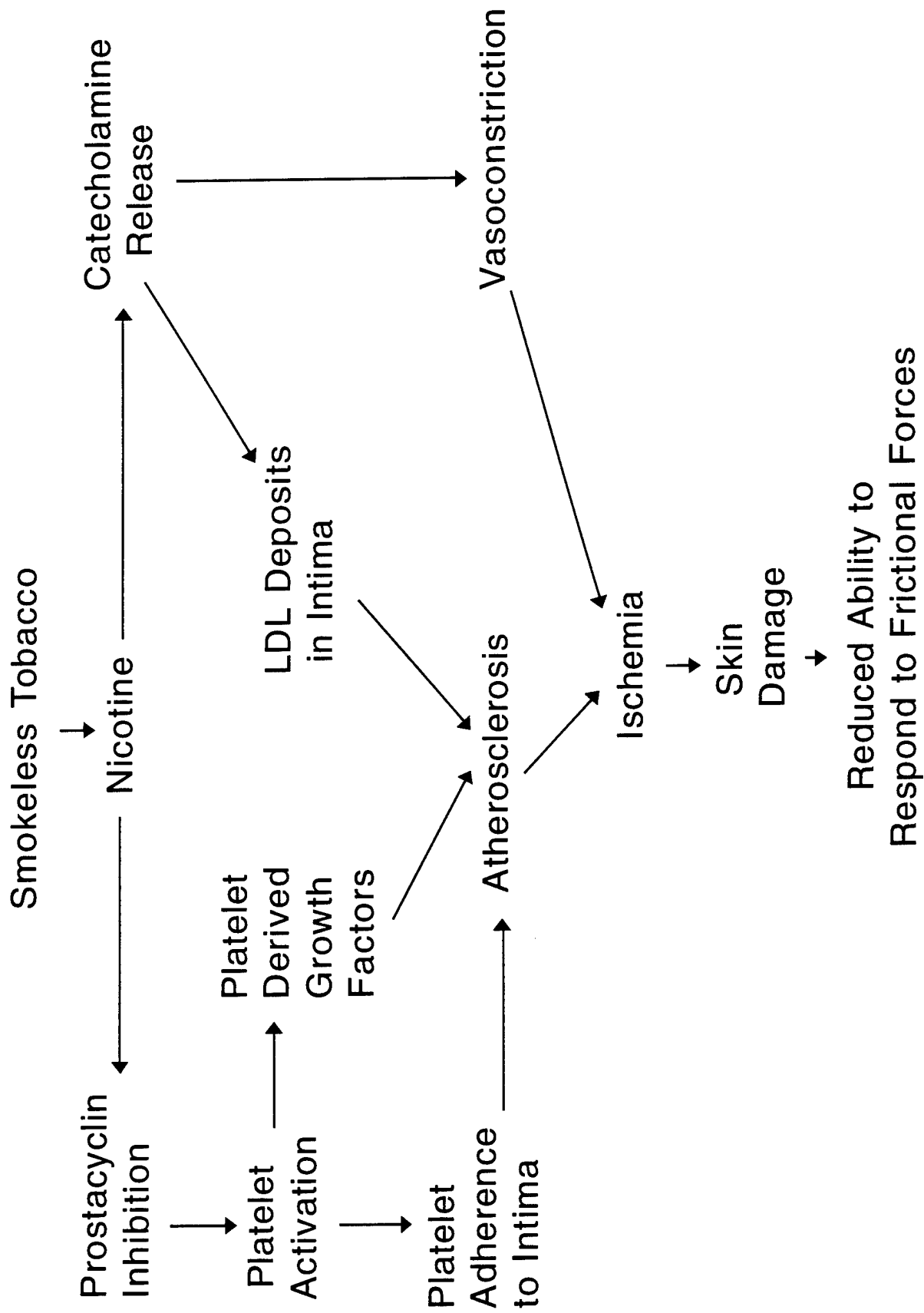


Figure 4. Hypothetical mechanism describing the influence of smokeless tobacco on friction blisters.

Montgomery, 1960; Rowe, Kilgore, & Robertson, 1980), smokeless tobacco (Schroeder, Bailey, & Sauvinsky, 1989) or smoking (Asano & Branemark, 1970; Reus, Robson, Zachary, & Heggers, 1984; Richardson, 1987; Rowe et al., 1980; Sarin, Austin, & Nickel, 1974; Waeber et al., 1984) causes vasoconstriction in the cutaneous circulation. In some cases, capillary blood flow can be totally blocked (Asano & Branemark, 1970). Evidence that nicotine is responsible for the vasoconstrictive effect comes from studies showing that sham smoking of unlit cigarettes or smoking of cigarettes without nicotine does not elicit changes in cutaneous circulation (Asano & Branemark, 1970; Richardson, 1987). The magnitude of the vasoconstriction depends on the dosage of nicotine, with larger dosages resulting a greater peripheral vasoconstriction (Asano & Branemark, 1970; Benowitz, Jacob, Jones, & Rosenberg, 1982; Dengerink et al., 1985; Richardson, 1987). Pigs (which have skin vasculature similar to humans) given twice daily intramuscular nicotine injections over a 5-week period had reduced skin capillary blood flow and elevated skin content of norepinephrine in surgically produced skin flaps (Forrest, Xu, & Pang, 1994).

In experimental studies, the cutaneous vasoconstrictive effect has been shown to last only a few minutes when only a single cigarette (Richardson, 1987) or bolus injection of nicotine (Dengerink et al., 1985) is studied. However, individuals who use tobacco products often maintain a steady plasma nicotine level (Benowitz, 1986; Benowitz et al., 1989; Russell & Feyerabend, 1978), suggesting that the vasoconstriction may be a chronic condition. With smokeless tobacco, plasma nicotine reaches levels similar to cigarette smoking but are sustained much longer; this may be because of the prolonged absorption that occurs with smokeless tobacco use (Benowitz, Porchet, Sheiner, & Jacobs, 1988).

In addition to the effects of nicotine on peripheral circulation, there is evidence that nicotine stimulates the development of atherosclerosis, mediated by actions of nicotine on catecholamine release and platelet activation. Catecholamines appear to have a direct effect on arterial walls (Helin, Lorenzen, Garbarsch, & Matthiessen, 1970), accelerating the deposit of low density lipoproteins into the intima (Born, 1991; Teplitz & Siwik, 1994). Rats or mice given nicotine in their drinking water over a 5- to 6-week period had a greater frequency of aortic endothelial cell death, decreased endothelial cell mitosis, and greater transendothelial leakage of albumin compared to controls (Lin, Hong, Chiang, & Chien, 1992; Zimmerman & McGeachie, 1987). Damage to endothelial junctions induced by nicotine (Booyse, Osikowicz, & Quarfoot, 1981; Boutet, Bazin, Turcotte, & Lagace, 1980; Zimmerman & McGeachie, 1987) may allow macromolecules (especially low density lipoproteins) to pass through the intima (Born, 1991;

Lin et al., 1992), resulting in fatty deposits between the intima and smooth muscle layer (Teplitz & Siwik, 1994).

In addition to catecholamines, nicotine may contribute to arterial lesions by its action on platelets. Nicotine may induce platelet activation by upsetting the balance between prostacyclin (PGI₂) and thromboxane A₂, which have antagonistic effects. Prostacyclin inhibits platelet aggregation and acts as a vasodilator, while thromboxane A₂ induces platelet aggregation and acts as a vasoconstrictor (Barrows, Ward, Sleightholm, Ritter, & Dollery, 1989; Teplitz & Siwik, 1994). Nicotine can inhibit the release of prostacyclin (Sonnenfeld & Wennmalm, 1980). In smokers, there are increased levels of urinary metabolites of thromboxane A₂, indicative of increased biosynthesis (Barrows et al., 1989).

Chronic smoking (Blache, Bouthillier, & Davignon, 1992; Hawkins, 1972; Renaud, Blache, Dumont, Thevenon, & Wissendanger, 1984; Sogani & Joshi, 1965) or tobacco chewing (Sogani & Joshi, 1965) induces platelet activation and decreases fibrolytic activity. This platelet activation appears to be attributable to nicotine (and not carbon monoxide) and the activation increases as the blood nicotine level increases (Renaud et al., 1984). Platelets can adhere to damaged intima in rats chronically exposed to cigarette smoke (Sieffert, Keown, & Moore, 1981), suggesting that platelets (or their by-products) may be involved in the fibrous deposits (Sogani & Joshi, 1965). In addition, blood platelet activity may be important in the development of atherosclerosis because of the numerous regulatory compounds they release, especially platelet-derived growth factors (Teplitz & Siwik, 1994).

Thus, the combination of nicotine-induced vasoconstriction in the peripheral circulation and atherosclerotic lesions may result in chronic ischemia in skin tissue. This may induce skin damage of a yet unspecified nature resulting in a reduced ability to respond to frictional forces (see Figure 4). That epidermal damage is induced by nicotine is further supported by data about facial wrinkling and skin flap survivability. Tobacco users have more than twice the risk of moderate to severe facial wrinkling (indicative of skin damage) when compared non-users, even after controlling for age, sun exposure, and body mass index (Ernster et al., 1995; Kadunce et al., 1991; Model, 1985). Both nicotine injection and smoking reduce the speed of skin healing and the survivability of surgically produced skin flaps (Forrest, Pang, & Lindsay, 1991; Forrest et al., 1994; Lawrence, Murphy, Robson, & Heggors, 1984; Mosely, Finseth, & Goody, 1978; Riefkohl, Wolfe, Cox, & McCarthy, 1986).

Sickness in Last 12 Months

Another blister risk factor was a self-report of one or more illnesses in the last year. We do not know the nature of the illnesses that cadets reported, but it might be assumed that any illness will challenge the immune system (Guyton, 1981). How this or some other factor could affect the epidermis and make blisters more likely is not clear. Future studies isolating specific illnesses that may be associated with blister likelihood, especially illnesses affecting the skin, may assist in further clarifying this association.

Previous Military Experience

The only independent risk factors for blisters in the antiperspirant group was no previous experience at a college military academy. Cadets who had previous military experience apparently were able to minimize march-related blisters. How this could have occurred remains unknown. This could be explored more fully in other investigations by asking more specific open-ended questions such as "Do you think your previous military experience helped you minimize blisters on this march? If so, how?"

Risk Factor Differences Between Antiperspirant and Placebo Groups

Antiperspirants appear to have altered blister risk factors because the risk factors were not the same in the antiperspirant and placebo groups. This could have occurred through a reduction in statistical power since blister incidence was substantially lower in the antiperspirant group. Three of the four risk factors (all but smokeless tobacco use) were in the same direction in both antiperspirant and placebo groups; that is, in the antiperspirant group, there was a tendency for other than black ethnicity, flat feet, and an illness in the last 12 months to have a higher incidence of blisters, but this tendency was not supported by the statistical analysis. Regardless of the mechanism, the use of antiperspirants considerably reduced the influence of the risk factors studied here.

CONCLUSIONS

Foot blisters have been a serious problem to military forces throughout history (West, 1895; Knapik et al., 1992). Previous studies have shown that blister likelihood can be reduced through the use particular sock systems (Knapik et al., 1996), and proper breaking in of boots (Patterson, Woolley, & Lednar, 1994). There is also a strong suggestion that regular physical training can reduce blister likelihood (Knapik et al., 1995). The present study suggests that if properly applied, antiperspirants can be added to the soldier's arsenal of preventive measures.

However, the irritating effects of the antiperspirant must be kept in mind and studies must be directed at better characterization of this effect. Methods of reducing irritation such as the use of lower dosages of aluminum chlorhydrate, alternations in the treatment schedule, or the use of cortisone in the antiperspirant preparation could be explored. The blister reduction effect of this particular antiperspirant appears relatively large, suggesting that adequate statistical power could be achieved with a small number of subjects in a controlled laboratory setting.

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APPENDIX A
BLISTER DATA SHEET

West Point Antiperspirant Study (8AUG96)

Name _____ SSAN _____

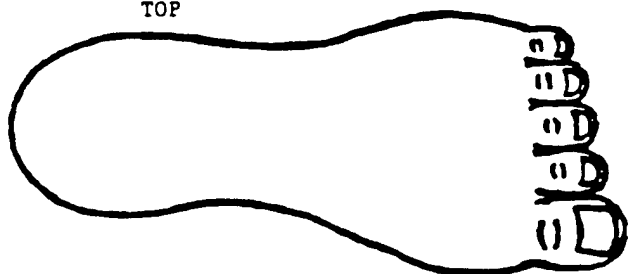
BLISTER (B)
BROKEN BLISTER (BB)
BLOOD BLISTER (BLB)
HOT SPOT (HS)

B BB BLB HS
Right Foot _____

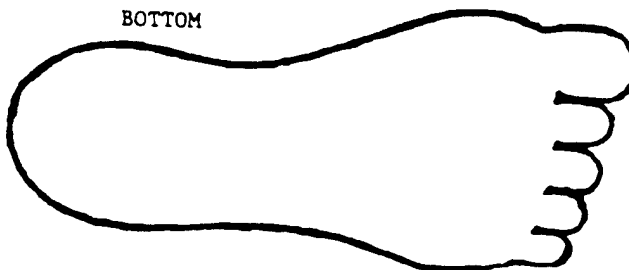
Left Foot _____

LEFT FOOT

TOP



BOTTOM



MEDIAL

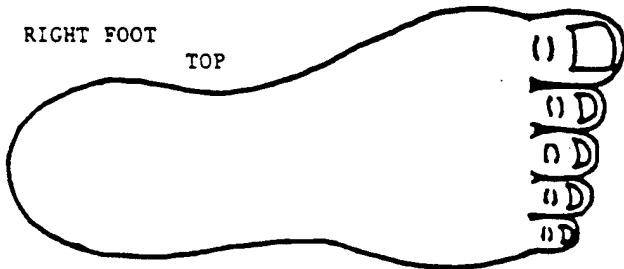


LATERAL

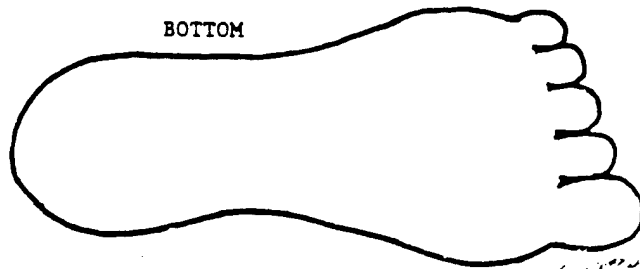


RIGHT FOOT

TOP



BOTTOM



MEDIAL



LATERAL



APPENDIX B
POST-MARCH QUESTIONNAIRE

POST-MARCH QUESTIONNAIRE

NAME _____ SSAN (Last 4 Digits) _____

A. Check the YES or NO blocks that apply:

1. Did you apply the preparation to both of your feet on each of these days before going to bed at night? (Today is 8AUG)

- | | |
|-----------------------------------|------------------------------------|
| a. Saturday (3AUG) YES ___ NO ___ | d. Tuesday (6AUG) YES ___ NO ___ |
| b. Sunday (4AUG) YES ___ NO ___ | e. Wednesday (7AUG) YES ___ NO ___ |
| c. Monday (5AUG) YES ___ NO ___ | |

2. Did you wear any of the following on your feet?

- | | |
|---------------------------------------|-------------------------------------|
| a. Moleskin YES ___ NO ___ | e. Petroleum jelly YES ___ NO ___ |
| b. Spenco second skin YES ___ NO ___ | f. Adhesive tape YES ___ NO ___ |
| c. Tincture of benzoin YES ___ NO ___ | g. Another material (specify) _____ |

B. Circle the letter(s) that apply:

1. What type of socks did you wear on the march?

- | | |
|----------------------------------|---|
| a. None | d. white cotton socks |
| b. Standard military green socks | e. Another type of sock (specify) _____ |
| c. Standard military black socks | _____ |

2. If you wore a second (inner) sock what type was it?

- a. I did not wear a second sock
- b. Standard military green sock as a second sock
- c. white cotton sock as a second sock
- d. Thin sock of synthetic material as a second sock (e.g., polypropylene, polyester, Coolmax, nylon, etc.)
- e. Another type of sock as a second sock (specify) _____

3. Did your feet sweat during the march?

- a. Yes b. No c. Not Sure

4. What type of boot did you wear on the march?

- a. Speed lace with padded ankle collar
- b. Lace up with eyelets
- c. Other (specify) _____

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